Technical Progress Report on Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration

Quarterly Report
January – March 2007

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ABSTRACT

The Nature Conservancy is participating in a Cooperative Agreement with the Department of Energy (DOE) National Energy Technology Laboratory (NETL) to explore the compatibility of carbon sequestration in terrestrial ecosystems and the conservation of biodiversity. The title of the research project is "Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration".

The objectives of the project are to: 1) improve carbon offset estimates produced in both the planning and implementation phases of projects; 2) build valid and standardized approaches to estimate project carbon benefits at a reasonable cost; and 3) lay the groundwork for implementing cost-effective projects, providing new testing ground for biodiversity protection and restoration projects that store additional atmospheric carbon. This Technical Progress Report discusses preliminary results of the six specific tasks that The Nature Conservancy is undertaking to answer research needs while facilitating the development of real projects with measurable greenhouse gas reductions. The research described in this report occurred between January 1st and March 31st 2007. The specific tasks discussed include:

- Task 1: carbon inventory advancements
- Task 2: emerging technologies for remote sensing of terrestrial carbon
- Task 3: baseline method development
- Task 4: third-party technical advisory panel meetings
- Task 5: new project feasibility studies
- Task 6: development of new project software screening tool

Work is being carried out in Brazil, Belize, Chile, Peru and the USA. Partners include the Winrock International Institute for Agricultural Development, The Sampson Group, Programme for Belize, Society for Wildlife Conservation (SPVS), Universidad Austral de Chile, Michael Lefsky, Colorado State University, UC Berkeley, the Carnegie Institution of Washington, ProNaturaleza, Ohio State University, Stephen F. Austin University, Geographical Modeling Services, Inc., WestWater, Los Alamos National Laboratory, Century Ecosystem Services, Mirant Corporation, General Motors, American Electric Power, Salt River Project, Applied Energy Systems, KeySpan, NiSource, and PSEG.

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EXECUTIVE SUMMARY

The Nature Conservancy, partners and collaborators continued to complete research and reports related to the tasks under this cooperative agreement. All work under this cooperative agreement is due to completed by the end of June, 2007. As much of the work has been completed and delivered on some tasks there is no progress to be reported.

Under tasks 1, 2, 3 and 6 there is no new work to report this quarter.

Under task 4, the final Technical Advisory Panel meeting was scheduled and planned. Over 60 people indicated they would attend the meeting, to be held on April 2 and 3, 2007.

Under Task 5, for the Northeast study this report contains a summary of Part 4, “Opportunities for Improving Carbon Storage and Management on Forest Lands.” Input from different internal and external reviewers was received. Using this input, alterations were made in the calculation of the area of land available for restocking of understocked stands. From this alteration, the amount of area, and therefore carbon sequestration potential, was reduced from original estimates. After taking all the reviews into consideration, the chapter was completed. This report also contains a summary of Part 5, “Environmental Co-Benefits of Carbon Sequestration Opportunities,” which has been completed for internal review. Part 5 analyzes the environmental co-benefits, which could be achieved in the study region through efforts to increase terrestrial carbon sequestration. Analysis is completed on the environmental co-benefits of afforestation activities in identified priority conservation areas. We previously planned to conduct analysis on restocking of understocked forests, but determined that it was not feasible due to the lack of special data on understocked forests. This report also contains work completed on Part 6, “Comparison of Opportunities,” which compares all the various sequestration opportunities analyzed in the previous parts of the report and summarizes opportunities based on quantity and cost. The work for part 6 is currently nearing completion. A final Part 7 of the report is also planned. Part 7 will be a summary for decision makers and will consist of a brief concise summary of the entire report. This section is meant to be presented in non technical terms and be easily understood by a broad audience of stakeholders interested in the findings of the report.

Also under Task 5, the feasibility study of carbon sequestration through reforestation in the Chesapeake Bay Watershed of Virginia was completed and delivered. This study identified several thousand sites on which reforestation activities could occur and would demonstrate significant climate change, emissions offset and biodiversity benefits. Many of these candidate sites are located in priority conservation areas identified by The Nature Conservancy. Additional analysis of sites reveals the potential for successful implementation of carbon sequestration projects.

EXPERIMENTAL

Task 1 Carbon Inventory Advancements

Carbon Inventories can be enhanced and costs lowered through improved techniques. Forest Inventories have been carried out for a number of reasons; to use for M3DADI calibration (Task 2), for use in carbon baseline development (Task 3) and for development of new regression equations and improved estimates of biomass for different terrestrial systems.

Task 2 Emerging technologies for remote sensing of terrestrial carbon

Research in California*: *Monitoring Forest Carbon and Impacts of Climate Change with Forest Inventories, High-Resolution Satellite Images, and LIDAR

Emerging remote sensing technologies, including high-resolution satellites such as QuickBird and Light Detection and Ranging (LIDAR), provide potential tools to scale up carbon estimates from hectare-scale forest inventory plots to landscapes of hundreds of square kilometers. The project tests the capabilities of three technologies, QuickBird 0.6 m resolution imagery, LIDAR, and digital videography to quantify aboveground forest carbon at three sites in the United States.

The project employs QuickBird and LIDAR in an applied research project "Monitoring Forest Carbon and Impacts of Climate Change with Forest Inventories, High-Resolution Satellite Images, and LIDAR." The project is a collaboration of the California Department of Parks and Recreation, Carnegie Institution of Washington, the Conservation Fund, Colorado State University, the Nature Conservancy, Stanford University, USDA Forest Service, U.S. Department of Energy, and the University of California, Berkeley.

Task 3 Carbon Baseline Method Development

The task involves developing and refining spatially explicit methods for estimating the carbon sequestration baseline for proposed forest conservation and reforestation projects at three sites in the United States and five sites in Latin America. The methods project possible future deforestation and reforestation trends and permit the calculation of carbon offsets from project activities.

Task 4 Third-Party Technical Advisory Panel Meetings

Standardizing measurement procedures and methods for carbon monitoring is a major step in the demonstration that land use projects should be creditable under any future regulatory mechanism. The Technical Advisory Panel (TAP) gathers a group of experts to evaluate existing methods and to develop standardized carbon offset measurement guidelines for use in all land-use change and forestry projects.

Task 5 New Project Feasibility Studies

While there seem to be a variety of project ideas that would lead to cost-effective sequestration and biodiversity projection, there has been little work accomplished to explore the feasibility of these ideas. Within the United States, we have yet to develop sound knowledge of the potential for implementing specific forestry and agricultural carbon sequestration projects. By assessing the cost and potential carbon benefits of different domestic projects we can learn more about how conservation and carbon sequestration projects may or may not be compatible.

Northeast Study

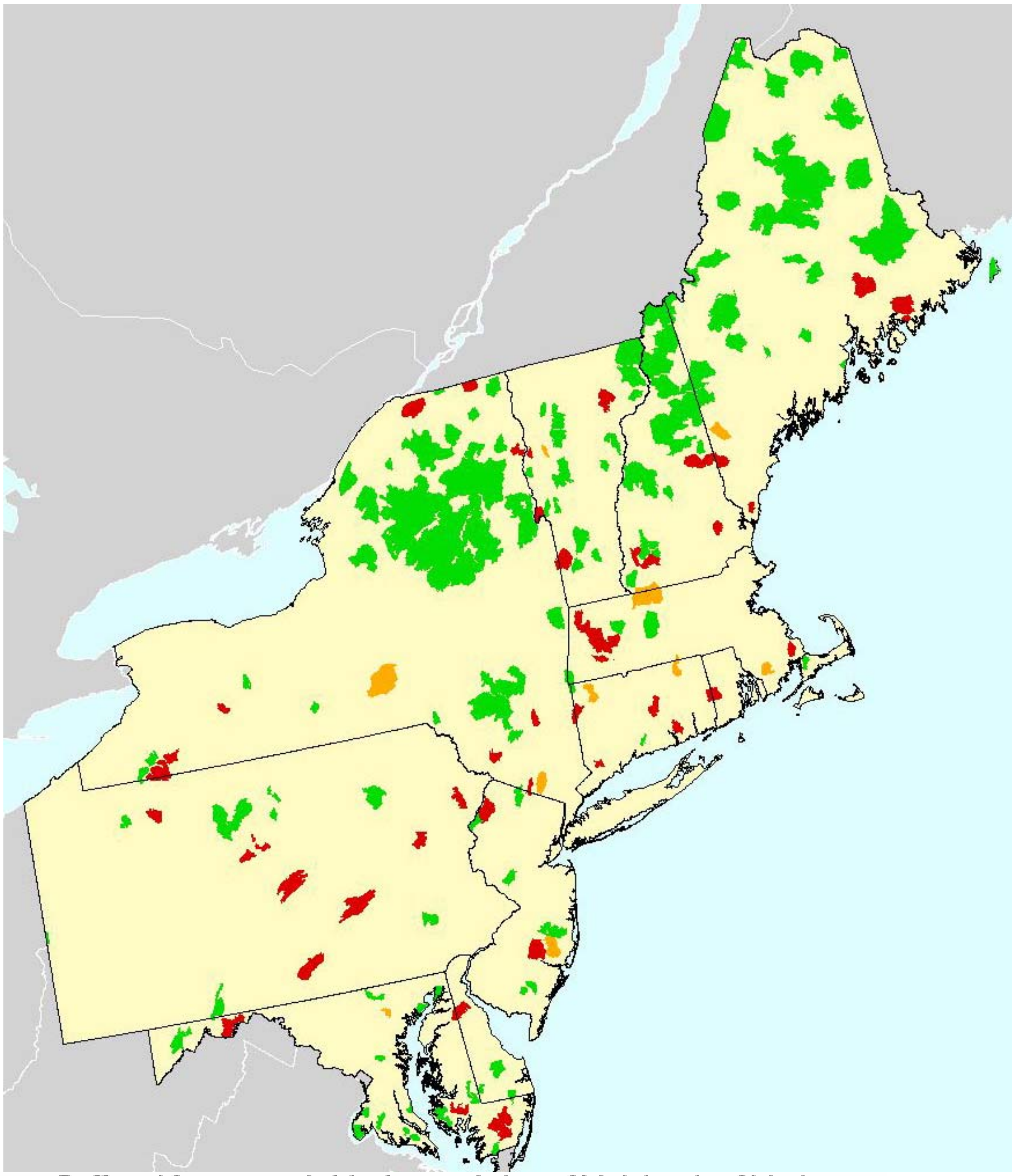
“Part 4: Opportunities for Improving Carbon Storage and Management on Forest Lands”

Part 4 of the report examines the potential of various forest management practices: extending rotations, restocking understocked stands, and increasing the riparian zone. This analysis is based on the US Forest Service Forest Inventory and Analysis program and an economic analysis. For the extending rotations, optimal rotational period was modeled, carbon sequestration was estimated, and an economic analysis was completed to estimate the impact of extending this rotational period. For the analysis on restocking understocked stands, the analysis considers only stands that are greater than 40 years only, and classified as poorly stocked or not stocked according to growing stock volume by the USDA Forest Service FIA. The revenue and cost streams analyzed are: harvesting existing stock and market merchantable component and current prices and costs, replanting potential natural vegetation on the site and harvesting forests in the future at 45 year intervals, and extracting marketable products at current market prices and costs. The change in carbon levels is then calculated along with an economic analysis to estimate the impact of restocking these stands. The final land management option assumes that land in a buffer along streams is conserved and not logged. The carbon gains in forests and costs associated with setting aside riparian zones in the Northeast is calculated along with the economic costs of such an action.

“Part 5, Environmental Co-Benefits of Carbon Sequestration Opportunities”

In carrying out the analysis for this report, two underlying major habitat types were chosen: forest habitats and freshwater habitats. As mentioned above, we used prioritizations developed by the Nature Conservancy for forest priority blocks and for priority streams and watersheds.

Forest matrix blocks, as identified by The Nature Conservancy, were selected for their size, natural land cover, and diversity of features, both biotic and abiotic. The conservation portfolio of forest matrix blocks was developed to identify those places that are the most critical to conserve. It reflects the understanding that some places play a more important role than others in maintaining biodiversity across the landscape. Particularly crucial are source habitats for interior forest species, complete and functional examples of common ecosystems, viable populations and breeding sites of rare species, and flowing stream systems connected from headwater to mouth. Figure 1 depicts the Conservancy’s current forest conservation regions and their corresponding conservation priority as depicted by the colors assigned to the areas. Prioritization was assigned according to the level of threat and environmental value of the forest habits. The green, orange and red colors assigned to the forest blocks represent their ranking according to their protection status. For example, blocks that are currently protected, the green areas depicted in the map, are given a lower rank than areas that are currently not protected, the red and orange areas. The red areas are considered to be of slightly greater environmental value than the orange areas. Forest matrix blocks are ranked by their level of threat and the level of threat is determined by their level of protection. It is assumed areas of less protection are in greater threat.



Buffered forest matrix blocks consisting of high levels of biotic endemism and abiotic diversity that reside in intact forest landscapes that have little or no protection

Buffered forest matrix blocks consisting of moderate levels of biotic endemism and abiotic diversity that reside in intact forest landscapes that have little or no protection

Buffered forest matrix blocks consisting of high levels of biotic endemism and abiotic diversity that reside in intact forest landscapes that are currently in a protected status

Figure 1

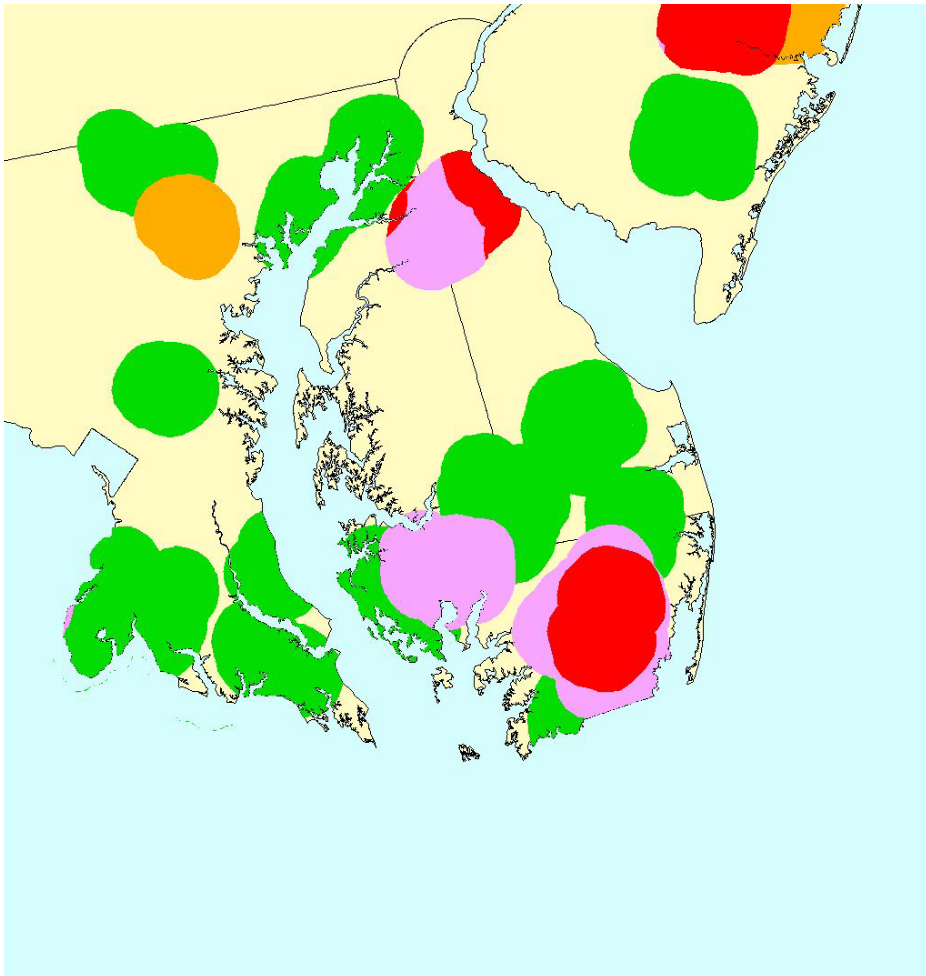
Figure 2 displays the priority rankings assigned to the forest matrix blocks by The Nature Conservancy scientists.

Priority 1 (pink area): Buffered forest matrix blocks consisting of high levels of biotic endemism and abiotic diversity that reside in degraded forest landscapes that have little or no protection.

Priority 2 (red area): Buffered forest matrix blocks consisting of high levels of biotic endemism and abiotic diversity that reside in intact forest landscapes that have little or no protection.

Priority 3 (gold area): Buffered forest matrix blocks consisting of moderate levels of biotic endemism and abiotic diversity that reside in intact forest landscapes that have little or no protection.

Priority 4 (green area): Buffered forest matrix blocks consisting of high levels of biotic endemism and abiotic diversity that reside in intact forest landscape and that are currently in a protected status.



Priority 1 — Buffered forest matrix blocks consisting of high levels of biotic endemism and abiotic diversity that reside in degraded forest landscapes that have little or no protection

Priority 2 — Buffered forest matrix blocks consisting of high levels of biotic endemism and abiotic diversity that reside in intact forest landscapes that have little or no protection

Priority 3 — Buffered forest matrix blocks consisting of moderate levels of biotic endemism and abiotic diversity that reside in intact forest landscapes that have little or no protection

Priority 4 — Buffered forest matrix blocks consisting of high levels of biotic endemism and abiotic diversity that reside in intact forest landscapes that are currently in a protected status

Figure 2

A conservation prioritization value was assigned to the streams and associated watersheds in the study region by aquatic scientists at The Nature Conservancy. All mid to large stream occurrences were systematically evaluated based on their size, condition, and landscape context. They also had their importance confirmed by experts during interviews performed state by state. Comprehensive information was compiled on each stream's biophysical setting, number of dams, distance to roads, number of toxic release points, land cover, and watershed condition. The final selection of critical streams reflected the knowledge and opinions of fisheries biologist, geomorphologists, mussel specialists, and others from academic, state, and federal institutions (Anderson, 2006).

For this study, stream buffer ranked classes are as follows and are depicted in Figure 3:

Priority 1: The most intact and functional streams and river networks of all size classes that represent the full spectrum of freshwater diversity in the region. For example this includes protection of critical habitats for spawning, feeding and growth of freshwater biota.

Priority 2: Critical intermediate size watersheds. These are the full watersheds for small and intermediate size streams that were assigned priority 1 classification. It is at this scale, that many processes critical to populations and communities occur (Fausch et al 2002).

Priority 3: Rivers and streams that are less in tact and function, but necessary to represent full suite of biodiversity and necessary to restore and maintain habitat connectivity important to for migratory fish species. These rivers and steams are also important to maintain water quality goals.

Priority 4: Intermediate size watershed of Priority 3 streams. These are watersheds needing restoration of connectivity or biodiversity.

Eastern United States Freshwater Biodiversity Areas

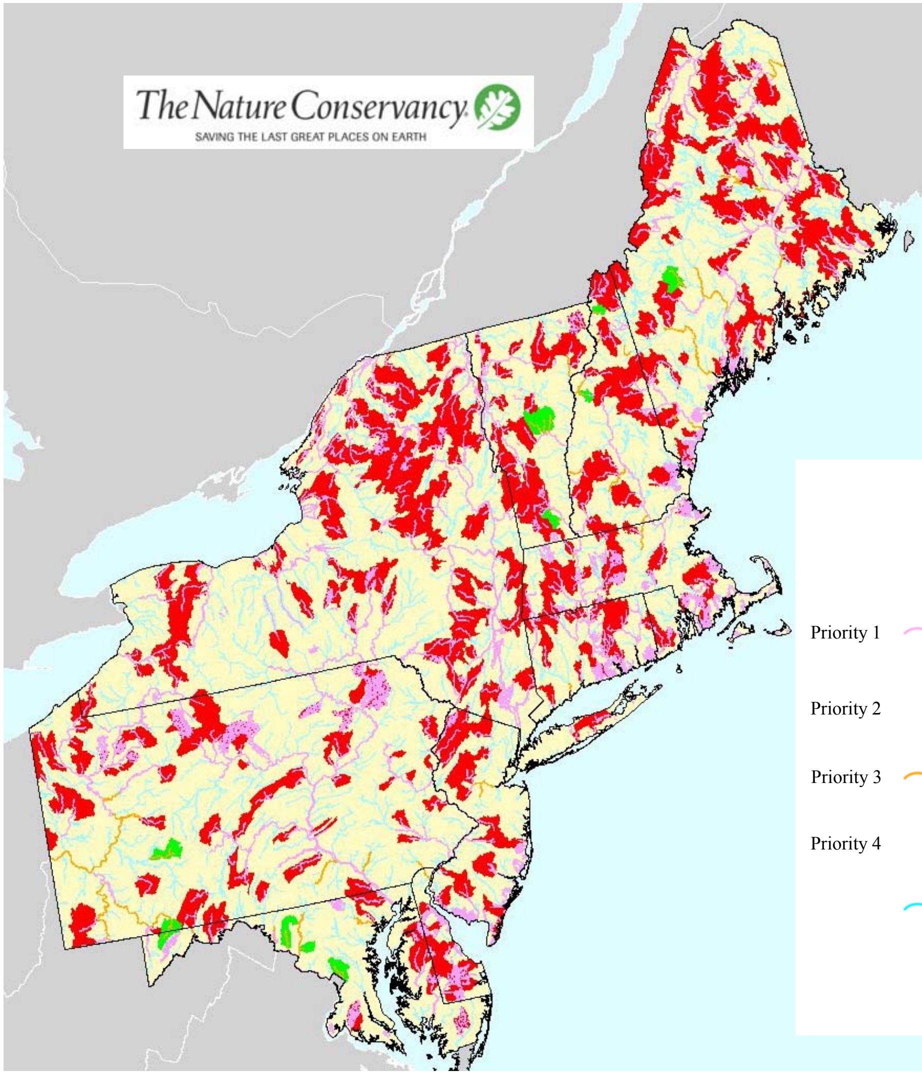


Figure 3

We identified the amount of crop and pasture lands in each of the priority ranked conservation areas to demonstrate how afforestation activities can result in a net increase of potential habitat thereby enhancing the conservation value of the lands through carbon sequestration activities.

We then used the spacial data on the quantity and cost of carbon from afforestation developed and reported in Part 3A of this report to determine the amount and cost of carbon of the activities to determine the potential quantity and corresponding cost of carbon in the areas identified as priority conservation areas.

Using data sources described in Part 3.3.2, we intersected cropland and pasture land spatial data with spatial data representing Nature Conservancy derived forest matrix blocks with a surrounding 10k buffer area and priority aquatic systems with a 200 meter (100 meter on each side) buffer. The result was polygon datasets showing the location and area of all crop and pasture land contained within forest matrix blocks and aquatic systems and their buffer areas. These intersected crop and pastured polygon areas were considered viable land units on which afforestation activities would have a high degree of conservation benefit. We spatially aggregated the intersected crop and pastureland units by county.

Using county scale per acre totals of tons CO2e described in section 3.4.3.3, we calculated the total potential tons CO2e for all lands within forest matrix blocks and priority aquatic areas classified as both crop and pastureland. The carbon accumulation measurements were calculated for 10, 20, and 40 years of growth.

"Part 6, Comparison of Opportunities"

The potential supply of CO_2e benefits from afforestation of crop and grazing lands is evaluated against converting to no-till, permanent vegetation, or even converting to biomass energy crops. On forest lands, the CO_2e potential of extending current forestry rotations, restocking understocked stands, and riparian buffers is compared with each other and, where appropriate, with land management options on current agricultural lands. Each of the land management options is compared in total and spatially across the region. Potential sequestration/emissions reductions and associated costs vary substantially spatially, and therefore by comparing each option on a county level, the most cost effective approach for a region can be elucidated. In the preceding sections of the report, land management options on current agricultural lands were examined at various points in time, however, in this comparison section, only data for a 20 year period are shown. Due to the nature of forestry land management, data presented are based on the assumption of a "permanent contract' meaning that once a land owner changed their management practice, it is assumed that the change would be permanent.

Reforestation in the Chesapeake Bay Watershed of Virginia

The project team developed a GIS-based protocol for identifying agricultural lands that could be reforested so as to sequester carbon and provide a number of environmental co-benefits. The project team identified agricultural lands that had been without forest since 1990, referencing the eligibility requirements for reforestation and reforestation carbon sequestration projects established under the Clean Development Mechanism of the Kyoto Protocol. This criteria is the most widely accepted eligibility metric for carbon sequestration projects at this time. Advances in carbon policy and carbon credit markets may influence the ultimate definition of lands eligible for carbon sequestration crediting programs.

To identify potential reforestation sites meeting the requirement of not being without forest cover since 1990, it was necessary to obtain land use classifications covering a period of pre-1990 to the present. Satellite imagery from the Landsat Thematic Mapper (Landsat 5 TM) and Landsat Enhanced Thematic Mapper Plus (Landsat 7 ETM+) were acquired for the following dates and paths:

- 2001 November 6 Path 15 / Row 33 & Path 15 / Row34
- 1988 September 23 Path 15 / Row 34
- 1987 May 16 Path 15 / Row 33

Using the GIS data, we applied several additional filters to the analysis. Specifically, we identified candidate sites which fall within TNC priority conservation areas. In the study area TNC is working to protect and restore forests and protect riparian buffers to ecologically significant stream and wetland systems. This effort is coordinated through the delineation of priority forest matrix blocks designed to protect large forested areas. Within forest matrix blocks, forest restoration should occur with a goal of reconnecting fragmented forest patches. TNC has delineated three forest matrix blocks in the study area: the Upper Rappahannock, Dragon Run, and Fort A.P. Hill.

Additionally, these data were used to produce an analysis of baseline changes in forest cover within the study period. The analysis distinguished the following:

- "candidate reforestation sites" = agricultural sites continuously without forest cover since 1990 or prior, through 2001
- "conservation priority candidate reforestation sites" = agricultural sites continuously without forest cover since 1990 or prior, through 2001, individual sites > 100 acres (a size adequate for conservation and forest management objectives), and location coinciding with TNC-delineated priority forest matrix blocks
- "baseline or business as usual reforestation (1987/88-2001)" = agricultural land without forest cover in 1987/88 (i.e. since 1990) and with forest cover in 2001
- "baseline or business as usual deforestation (1987/88-2001)" = with forest cover in 1987/88, and without forest cover and with a conversion of land use to agriculture or urban in 2001

Task 6 Development of new project software screening tool

Carbon measurement and monitoring costs are unique transaction costs for forest-based carbon sequestration projects. Project developers need to weigh the costs of carbon measurement and monitoring against the potential benefits of the sale of carbon offsets (carbon revenue). Carbon benefit data from USDA Forest Service inventories will be combined with carbon measurement and monitoring variables in a spreadsheet-based tool to allow users to compare potential carbon costs and revenues on a project level.

RESULTS AND DISCUSSION

Under tasks 1, 2, 3 and 6 there is no new work to report this quarter.

Task 4 Third-Party Technical Advisory Panel Meetings

The final Technical Advisory Panel meeting was scheduled and planned. Over 60 people indicated they would attend the meeting, to be held on April 2 and 3, 2007.

Task 5 New Project Feasibility Studies

Northeast Study

"Part 4: Opportunities for Improving Carbon Storage and Management on Forest Lands"

Extending Rotations:

There are around 2.2 million acres of forest land available for extending rotations. Five year rotation extensions are the most cost effective option. The results of the analysis indicate that there are potentially substantial opportunities for increasing carbon sequestration through aging in NE softwood forests. For 5 year rotation extensions, around 2.9 million t C (discounted) could be sequestered for up to \$6/t CO_2e (Table 1). The lowest cost opportunities appear to be site class 5 for both white-red-jack pine and spruce-fir forests. This amounts to about 3.8 t C/ha.

Table 1. Summary of C sequestration opportunities softwoods for 5, 10, and 15 year extensions in rotation ages in Maine, New Hampshire, New York, and Vermont. The analysis if for Permanent Storage (discounted carbon) on private land only.

	Total Tons	Total Cost	Cost per ton
5 Year Extension	1000 tons C	Million \$	Avg. \$/tCO_2e
White-Red Jack Pine Site Class 3	95.5	\$3.4	\$9.69
White-Red Jack Pine Site Class 4	431.6	\$13.2	\$8.32
White-Red Jack Pine Site Class 5	732.2	\$13.1	\$4.86
White-Red Jack Pine Site Class 6	511.9	\$10.6	\$5.64
Spruce-Fir Site Class 3	48.5	\$1.0	\$5.45
Spruce-Fir Site Class 4	305.8	\$6.7	\$5.93
Spruce-Fir Site Class 5	576.4	\$9.2	\$4.35
Spruce-Fir Site Class 6	520.7	\$19.6	\$10.25
Total	3,222.6	\$76.7	\$6.48

To get a sense for the spatial distribution of these potential activities, the average costs for 5 year rotation extensions are shown in Fig 4. As with the stocking results plotted above, there are a number of counties in the four states examined where there are apparently no opportunities to increase carbon through aging softwoods. This occurs because these counties either have no pine or spruce-fir stands, or they have no stands in the requisite 40 - 60 year old age classes. Total carbon (permanent carbon discounted over 300 years) that can be sequestered in each county for <\$10/t CO_2e is plotted by county in Fig. 4-2. The largest potential appears to occur in Maine, but of course, this partly results from the relatively large counties in that state.

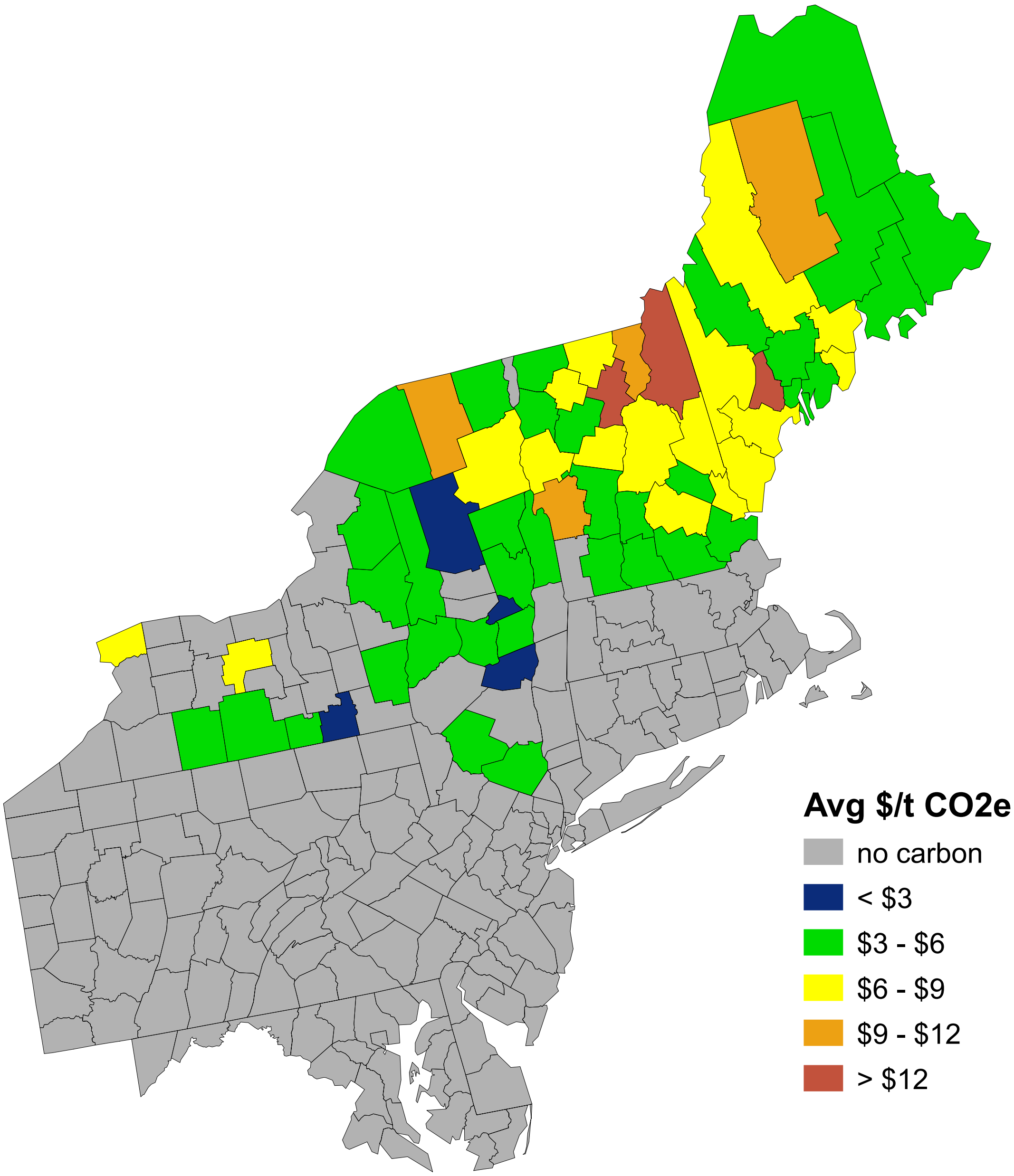


Figure 4. Average cost per t CO_2e for sequestering carbon in 5 year rotation extensions in softwoods of four northeastern states (Maine, New Hampshire, New York, and Vermont). (Permanent contract; private lands only; discounted carbon over 300 years; r=6%).

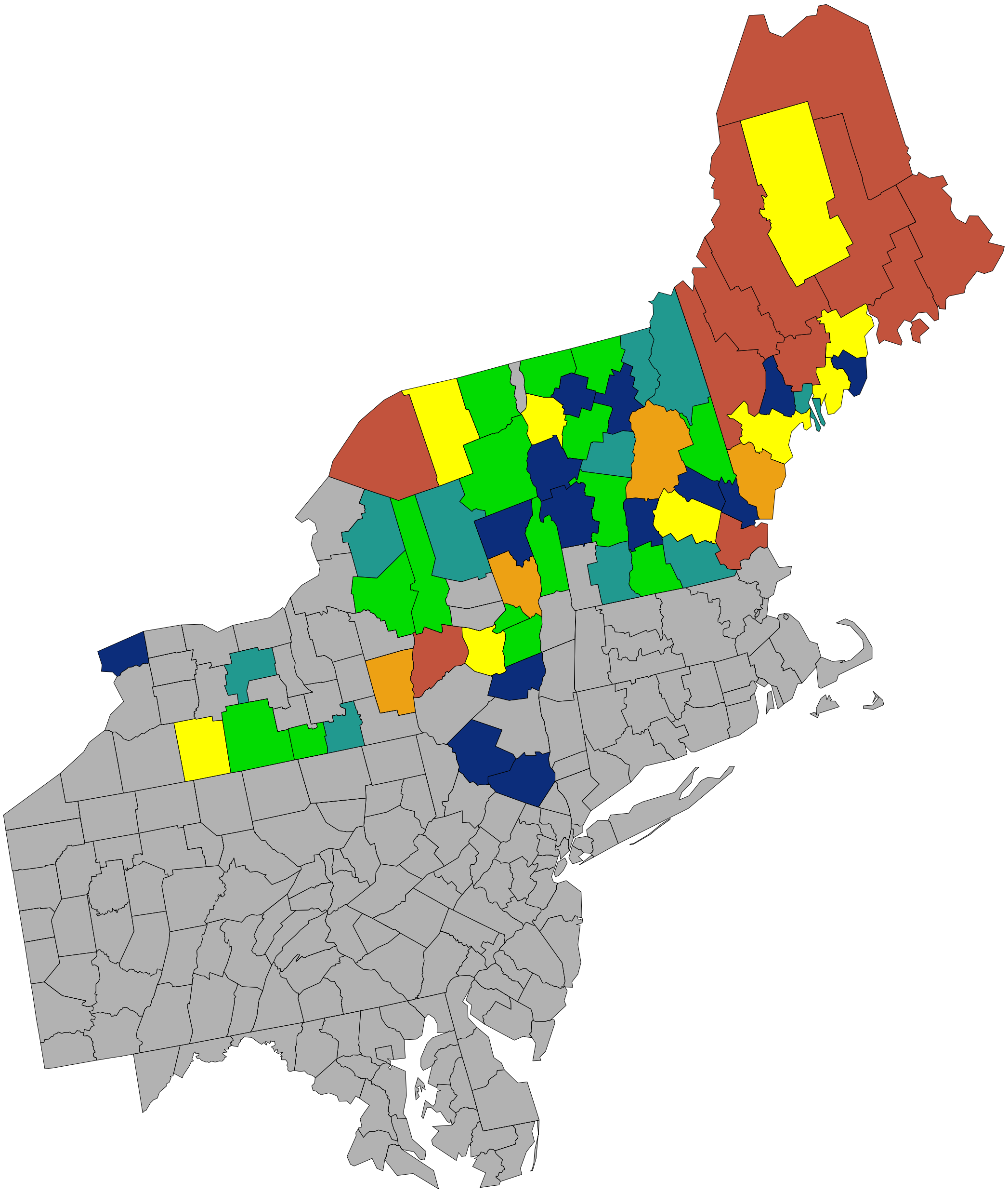


Figure 5. Total carbon potentially sequestered by county in four northeastern states only (Maine, New Hampshire, New York, and Vermont) for aging forests 5 years where marginal costs are <\$10/t CO_2e. (Permanent contract; private lands only; discounted carbon over 300 years; r=6%).

Increasing the Stocking of Under-stocked stands:

Poorly- and under-stocked forests greater than 40 yr of age encompass approximately 4.6 million acres in the Northeast region. Under current levels of stocking, there are approximately 77.7 million t C on poorly and non-stocked stands (17 t C/acre). Full stocking of these stands could in the future bring the total carbon stored in these forests to 171 million t C (37 t C/acre) over a 300 year period. There are consequently substantial potential C benefits associated with increasing the stocking density. This section provides an examination of the potential to convert these poorly- and non-stocked stands from their current conditions to fully stocked conditions.

To give a sense for the potential sequestration across the states and forest types, Table 2 presents average \$/t CO_2e, total potential t C, and total potential area with positive sequestration for each forest type, for the 300 year permanent contract with carbon discounted at r=6%. The results suggest that the lowest cost options exist with Maple Beech Birch (MBB), Oak Pine (OP), and Oak-Hickory (OH). Maple Beech Birch in particular has high values for some of the maple types (Sugar Maple), and thus there are strong values associated with regenerating well stocked stands. On about 403,900 acres, around 0.7 million t C could be sequestered in the MBB type, and on 534,300 acres, 1.4 million t C could be sequestered in Oak-Hickory types for relatively low or no cost. The states with the least average cost are Pennsylvania, Delaware, New Jersey, and New York.

Table 2. Carbon sequestration potential, average costs, and acres in program from harvesting and regenerating poorly stocked stands in The Northeast. Estimates are for permanent 300 year contracts, and carbon changes are discounted (r=6%) over the entire time period. Estimates only include acres for which there are positive carbon benefits. Numbers in parentheses indicate that the projects would potentially generate profits of the indicated values over the cycle.

	WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]	Total
Average $/t CO_2e									
CT	$124	--	--	($2)	--	$235	$179	--	$76
DE	--	--	--	($12)	--	$2	--	--	($9)
ME	($6)	$13	($159)	($25)	--	$13	--	--	$6
MD	--	--	--	--	--	--	--	--	--
MA	$50	--	($21)	($3)	--	$163	--	--	$23
NH	$38	--	--	--	--	$5	($14)	--	$9
NJ	--	--	--	($9)	--	$10	($73)	--	($24)
NY	$14	--	($37)	($18)	--	$13	($271)	--	($50)
PA	$25	$6	($469)	$2	$12	$6	($128)	$281	($35)
RI	--	--	--	$31	--	$151	--	--	$57
VT	$15	$10	--	--	--	($6)	($160)	--	$3
Total	$8	$12	($51)	($2)	$12	$12	($142)	$281	($21)
Potential Tons Stored in State (permanent 300 year contract – discounted carbon)									
Thousand t C									
CT	2.7	--	--	12.7	--	5.0	0.7	--	21.1
DE	--	--	--	49.5	--	12.4	--	--	61.9
ME	210.9	647.8	7.3	20.1	--	45.1	--	--	931.3
MD	--	--	--	--	--	--	--	--	--
MA	14.0	--	1.8	32.9	--	4.1	--	--	52.9
NH	17.5	--	--	--	--	32.1	17.3	--	66.9
NJ	--	--	--	85.0	--	58.9	65.2	--	209.0
NY	122.6	--	60.9	178.9	--	153.7	107.9	--	623.9
PA	29.9	16.6	0.3	979.5	20.6	138.8	496.8	2.5	1,685.1
RI	--	--	--	10.1	--	2.8	--	--	12.8
VT	45.8	210.0	--	--	--	60.0	8.9	--	324.7
Total	443.4	874.4	70.4	1,368.6	20.6	512.9	696.8	2.5	3,989.6
Acres Potentially in Program									
Thousand Acres									
CT	3.5	--	--	1.7	--	11.1	6.6	--	23.0
DE	--	--	--	7.6	--	3.5	--	--	11.1
ME	65.8	292.4	5.7	5.7	--	11.7	--	--	381.3
MD	--	--	--	--	--	--	--	--	--
MA	6.5	--	0.9	6.6	--	6.3	--	--	20.3
NH	6.8	--	--	--	--	7.8	31.1	--	45.7
NJ	--	--	--	25.9	--	19.5	18.6	--	64.0
NY	27.4	--	30.4	73.6	--	42.5	116.1	--	289.9
PA	6.5	1.8	1.6	407.2	7.6	35.5	224.6	6.5	691.1
RI	--	--	--	6.0	--	3.7	--	--	9.8
VT	11.9	45.7	--	--	--	7.1	6.8	--	71.5
Total	128.3	340.0	38.5	534.3	7.6	148.6	403.9	6.5	1,607.6

([1]) WRJ Pine = White, Red, and Jack Pine; SF = Spruce and Fir; OP = Oak-Pine; OH = OakHickory; OCG = Oak-Gum-Cypress; EAC= Elm-Ash-Cottonwood; MBB = Maple-Beech-Birch; AB = Aspen and Birch.

The results indicate that up to 2.9 million t C (10.6 million t CO_2e) could be sequestered for less than $10/t CO_2e, with many of these project activities generating net benefits. The regional distribution of the carbon opportunities with costs less than $10/t CO_2e is shown in Figure 6. The largest opportunities appear to occur in Maine, followed by Pennsylvania and by New York. This is not surprising as these states have the most total forestland area.

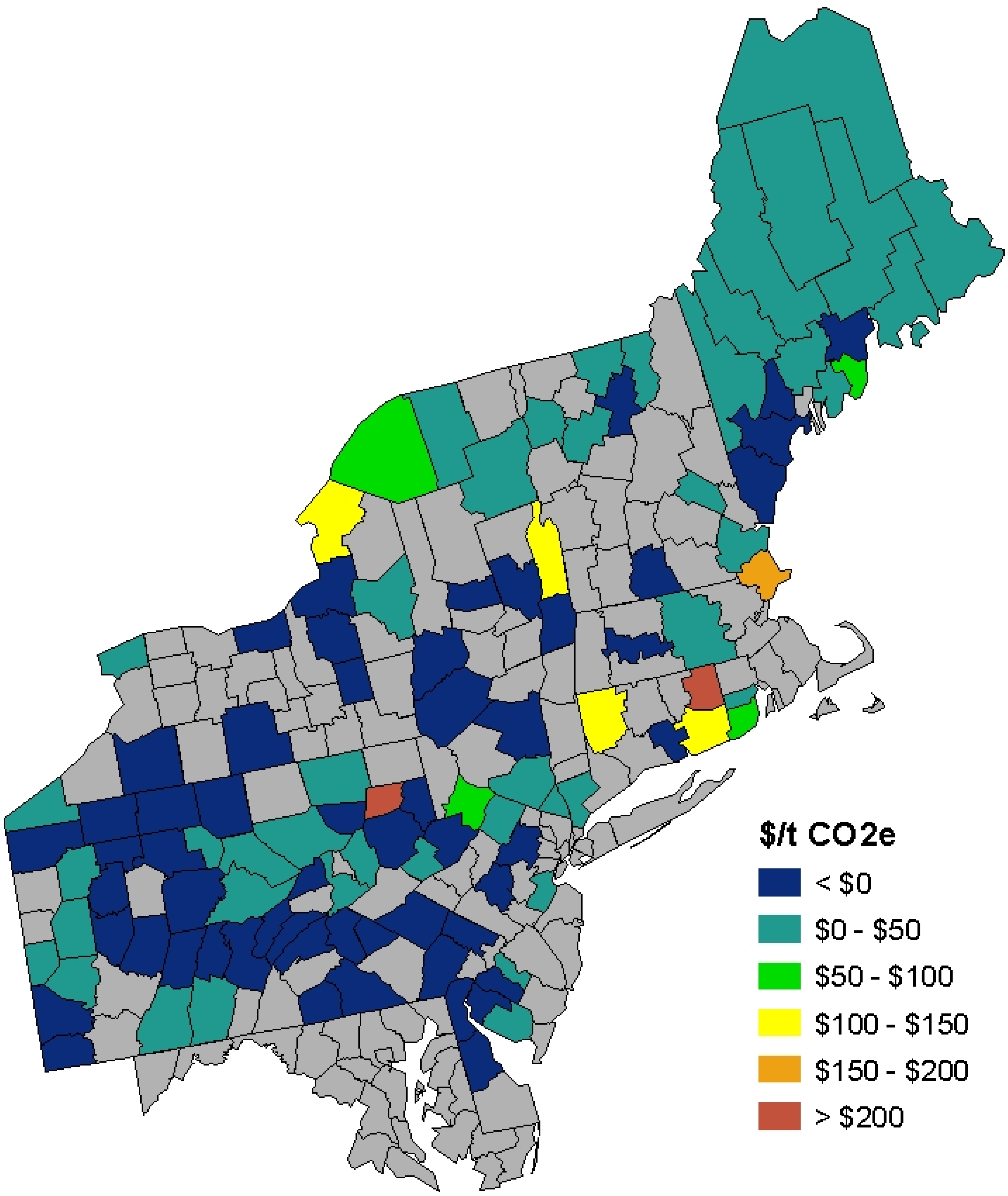


Figure 6. Average cost of carbon sequestration in each county from improving stocking conditions in poorly stocked forests. Estimates for permanent 300 year contract with discounted carbon (r=6%)

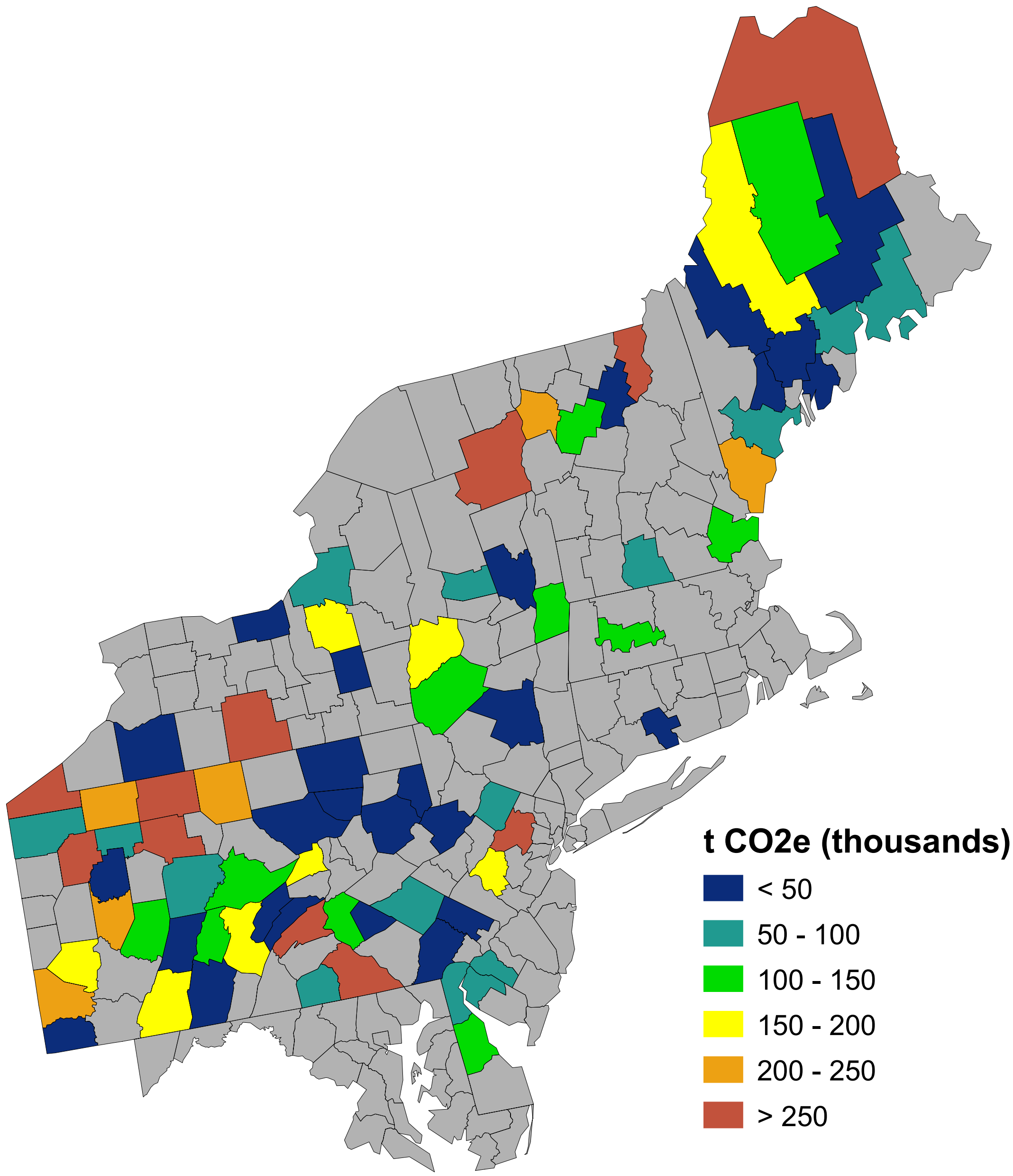


Figure 7. Total carbon potential for poorly- and under-stocked stands by county at marginal costs of less than $10/t CO_2e. Estimates are for permanent 300 year contract with discounted carbon (r=6%).

"Part 5, Environmental Co-Benefits of Carbon Sequestration Opportunities"

Total acres available for afforestation of cropland and pasture land in the defined priority ranked conservation areas is depicted in Table 3.

Table 3

Land Area Available for Carbon Sequestration Potential of Cropland Depicted by Habitat Type and Priority Ranking (area = acres)

	FM 1	FM 2	FM 3	FM 4	FM Total	SB 1	SB 2	SB 3	SB 4	SB Total
CT	1,492	23,528	12,346	4,162	41,529	3,291	33,501	43	0	36,836
DE	48,225	32,390	0	219,000	299,615	12,424	270,841	0	0	283,265
MA	1,246	32,346	27,216	39,149	99,957	7,769	75,212	274	0	83,255
MD	184,534	104,022	30,402	429,905	748,863	14,520	367,619	0	0	382,139
ME	0	10,605	243	101,874	112,722	1,282	38,265	759	17	40,305
NH	0	2,012	550	5,710	8,271	1,762	986	439	50	3,187
NJ	16	12,324	141	10,830	23,310	2,056	27,609	76	0	29,742
NY	6,550	74,260	21,053	192,358	294,221	22,378	323,525	45	0	345,947
PA	6,300	49,459	0	22,390	78,149	10,909	202,162	490	0	213,560
RI	0	3,779	436	0	4,214	293	8,266	0	0	8,559
VT	4,922	57,317	13,746	140,718	216,704	11,185	145,060	764	20,553	157,009

Land Area Available for Carbon Sequestration Potential of Pastureland Depicted by Habitat Type and Priority Ranking (area = acres)

	FM 1	FM 2	FM 3	FM 4	FM Total	SB 1	SB 2	SB 3	SB 4	SB Total
CT	2,832	64,176	30,240	16,508	113,756	5,815	85,755	37	0	91,606
DE	475	124	0	996	1,595	168	1,113	0	0	1,281
MA	5	15,437	13,420	13,616	42,479	2,979	31,770	72	0	34,821
MD	6,039	10,079	10,377	63,639	90,133	3,359	37,095	3,032	0	43,486
ME	0	59,938	19,892	235,275	315,105	11,263	212,732	0	1,783	225,778
NH	0	36,255	5,541	71,136	112,932	4,827	41,038	607	4,517	50,988
NJ	0	0	0	0	0	0	0	0	0	0
NY	23,429	293,919	119,935	752,357	1,189,641	53,078	1,181,093	308	0	1,234,478
PA	36,452	394,152	0	222,827	653,431	42,058	1,032,181	2,244	0	1,076,484
RI	0	3,193	389	0	3,581	325	3,970	0	0	4,295
VT	5,151	45,562	9,790	93,421	153,924	3,540	75,736	348	8,669	88,294

FM[1]= Forest matrix; [1]= priority ranking
SB = Stream buffer

The total of tons of CO2e by county from afforestation of cropland to benefit forest conservation is shown in Figure 8. Similar maps for afforestion of cropland to benefit stream conservation and afforestation of pasture land to benefit priority conservation activities are included in the study.

Tables 4 and 5 show the total potential tons of CO2e that could be sequestered through afforestation of cropland and pasture land respectively over 10, 20 and 40 years and at various costs: $7; 10; $20; $40; $50/ton CO2e. Potential tons of CO2e estimated to cost greater than $50/ton CO2e is not shown. The total potential CO2e/ton at each price point was derived by summing all the potential CO2e at or below the stated price level. Totals are reported for both forest and aquatic priority conservation areas.

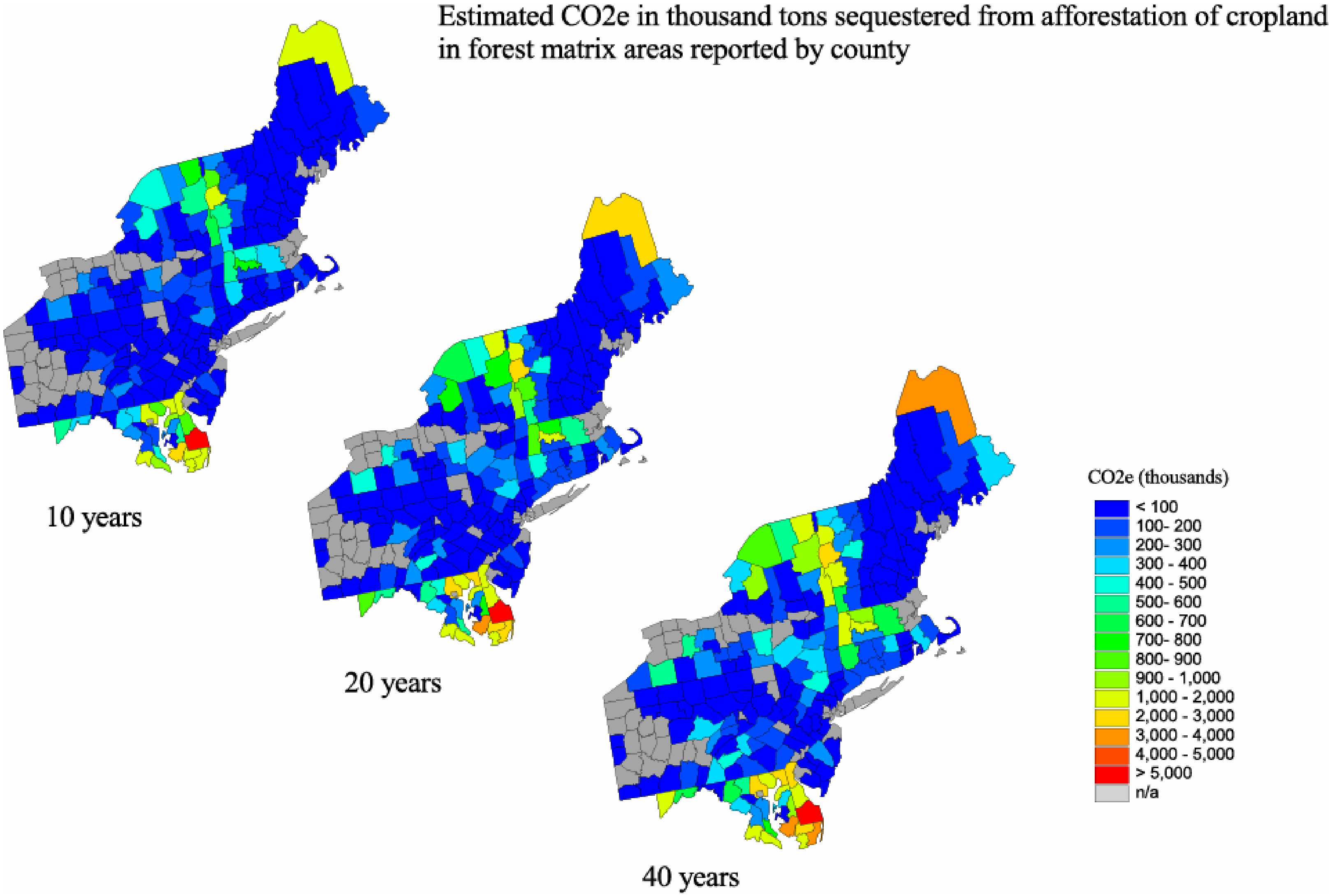


Figure 8. Estimated CO2e in thousand tons sequestered from afforestation of cropland in forest matrix and buffer areas over 10, 20 and 40 years.

Table 4

Estimated Total Potential tons of CO2e From Afforestation of Cropland						
	Forest Matrix 2,876 acres available			Stream Buffer 1,572 acres available		
	10 years	20 years	40 years	10 years	20 years	40 years
$7/ton CO2e	0	0	0	0	0	0
$10/ton CO2e	0	0	0	0	0	0
$20/ton CO2e	0	0	0	0	0	0
$40/ton CO2e	12,078	18,127	22,016	13,476	20,224	24,564
$50/ton CO2e	14,526	103,273	117,654	14,437	58,647	65,569

Table 5

Estimated Total Potential tons of CO2e From Afforestation of Pasture land						
	Forest Matrix 1,464,981 acres available			Stream Buffer 1,100,008 acres available		
	10 years	20 years	40 years	10 years	20 years	40 years
$7/ton CO2e	103,493	2,896,230	3,544,927	2,095	1,069,143	1,309,147
$10/ton CO2e	103,493	2,896,230	4,286,766	2095	1,069,143	1,758,481
$20/ton CO2e	2,284,196	3,793,640	6,558,80	859,491	2,288,655	4,361,654
$40/ton CO2e	9,180,631	30,696,207	47,034,885	6,658,129	21,276,422	31,631,856
$50/ton CO2e	25,950,046	46,823,799	57,019,595	17,862,771	35,394,867	44,331,324

"Part 6, Comparison of Opportunities"

All of the changes in land management examined here result in carbon dioxide sequestration and in some case reductions in carbon dioxide emissions. Converting croplands to afforestation has the potential to accumulate the largest amount of carbon per unit land area through the growth of trees. Changes in other carbon pools such as soil, litter, and deadwood were not included in the analysis but are expected to increase or not decline significantly over time (as in the case of soil carbon on grazing lands converted to afforestation). Conversion to no-till or to permanent vegetation include carbon emission changes through altered farming practices and thus reduced emission and soil carbon sequestration. On a per unit area basis, carbon sequestration/emission reduction from conversion of cropland to no-till or to pasture is small, and about a quarter or less of that for afforestation. Estimates of the sequestration/emission reductions associated with converting to biomass energy production include the growth of the biomass, the displacement of fossil fuels, and the increase belowground carbon. Production of biomass energy has high carbon emission reduction potential per unit area, however, due to the scarcity of data on biomass production potential (essentially one value across the region, without taking into account regional differences in growing season length), the applicability of this estimate across the region is not well known and should be treated with caution.

The potential carbon sequestration/emission reduction equivalence per unit area can then be used to estimate the amount of land needed to attain a given supply of CO_2e. Because the carbon sequestered per unit area for afforestation and biomass energy production is relatively high, the area of land needed to result in given quantity of CO_2e is small compared to other land management activities. Changing management of forests requires the most land to reach a given supply of CO_2e.

The estimated maximum potential supply of CO_2e for the region through afforestation or biomass energy production is substantial, due to both the high sequestration/emission reduction per unit area and the large area of agricultural land. If all the agricultural land in the region was afforested, the potential estimated CO_2e sequestered over 20 years would equal 17% of the 2005 greenhouse gas emissions of the United States (Energy Information Administration, DOE 2006). The maximum potentials are significantly lower for other land management options. A scenario in which all agricultural land or forest land is converted to one land management strategy is highly unlikely, and so the total possible maximum is presented only to illustrate the management style's overall maximum capacity. Because afforestation has the greatest per unit area potential (if biomass energy is excluded), afforestation is the land management option with the largest potential within each county.

Although afforestation and biomass energy produce the greatest quantity of t CO_2e, they are not the land management strategy with the lowest marginal costs (Table 6). Costs vary substantially by county, and restocking understocked forests and forest rotation extension both provide the option with the lowest overall marginal costs (Figure 9). As a reminder, the analysis on extending rotations only took place in Maine, New Hampshire, New York, and Vermont. Converting to no-till agricultural, on average, presents the management type with the lowest marginal costs on agricultural lands because the existing practice does not need to change. For some counties in the more southerly states, conversion to perennial vegetation is the most cost effective management practice. For most of the counties where riparian buffers presents the best option, this is because either there is no other land management option, or because it is a more cost effective option than no till.

Table 6. Area weighted mean marginal costs for all land management options

Assuming 20 year period on agricultural lands, and permanent land management change on forest lands. Note means slightly different than Table 4-18 due to differences in resolution of means.

	Agricultural Lands					Forest Lands		
	Afforestation of Cropland	Afforestation of Pasture	No-till	Permanent Vegetation	Biomass Energy	Restocking understocked Stands	5 year Rotation Extension	Riparian Buffer
	$/t CO_2e							
Connecticut	87	52	18	168	29	404		26
Delaware	70	52	22	120	28	-6		
Maine	100	31	11	168	32	11	6	150
Maryland	121	97	22	53	25			
Massachusetts	87	51	14	130	27	65		34
New Hampshire	98	50	12	138	30	-3	8	103
New Jersey	100	82	23	85	21	-1		4
New York	99	48	19	178	26	-214	5	101
Pennsylvania	107	84	19	140	28	-58		28
Rhode Island	100	78	19	104	27	57		28
Vermont	90	40	14	165	28	-7	7	99
All States	**103**	**64**	**18**	**139**	**27**	**-53**	**6**	**84**
Minimum	36	13	10	-137	12	-1,434	3	0.11
Maximum	254	265	29	348	38	693	21	240

* Negative numbers in average cost estimates indicate that the projects would potentially generate profits over the cycle.

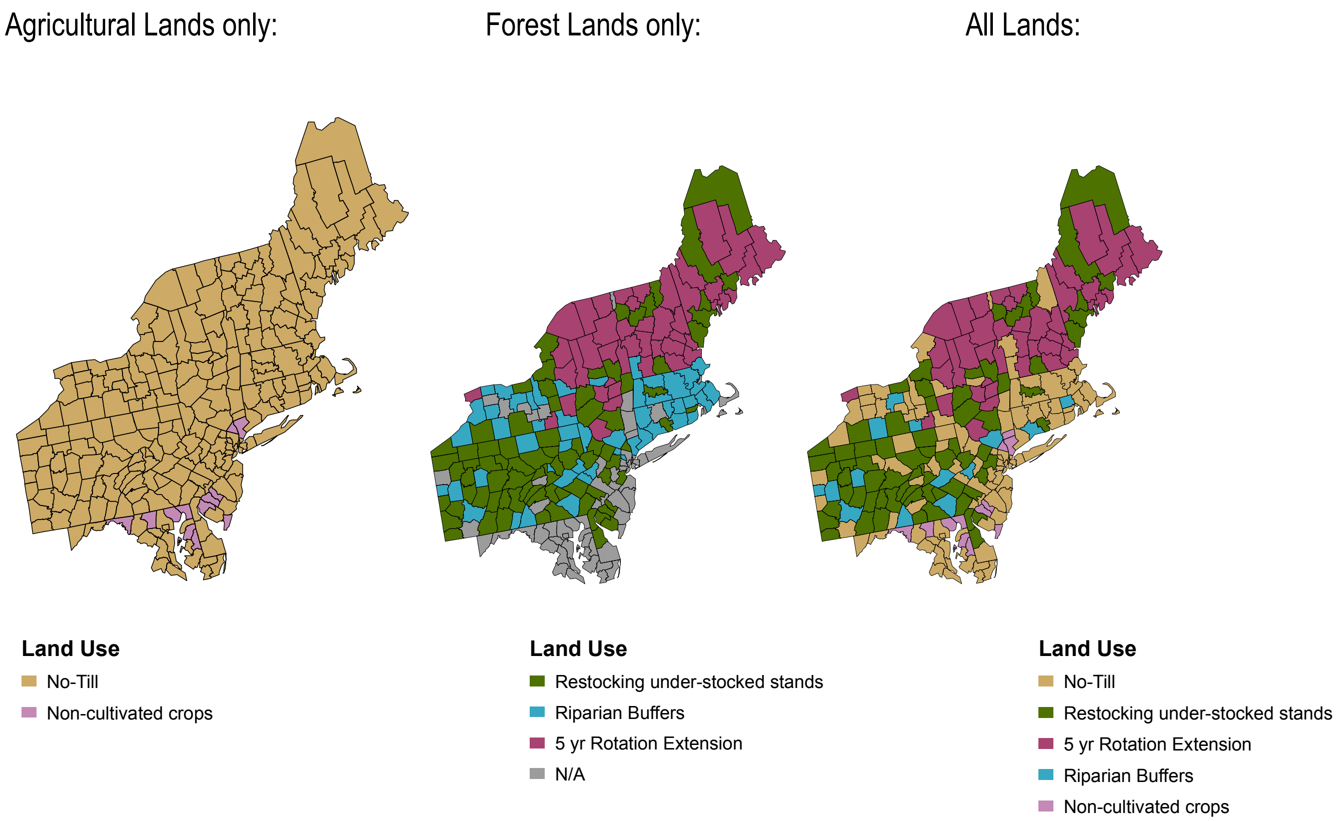


Figure 9. Land management option with lowest marginal cost (\$/ton CO_2e)
Assuming 20 year period on agricultural lands, and permanent land management change in forest lands
Biomass energy excluded from comparisons

At specified price points, the maximum amount of land economically available and the total maximum potential sequestered t CO_2e for each land management strategy can be calculated. As a result of the high marginal costs, very little area is available or potential CO_2e sequestered for afforestation until higher prices levels would be reached. However, conversion to permanent vegetation and all forest management options are economically attractive land management strategies on large areas of lands at prices as low as \$7/t CO_2e.

The land management option with the lowest costs and highest potential can be identified for each count (Figure 10). At lower prices, forest management is the best option however at larger marginal costs no-till and afforestation of pastureland can provide large amounts of land available.

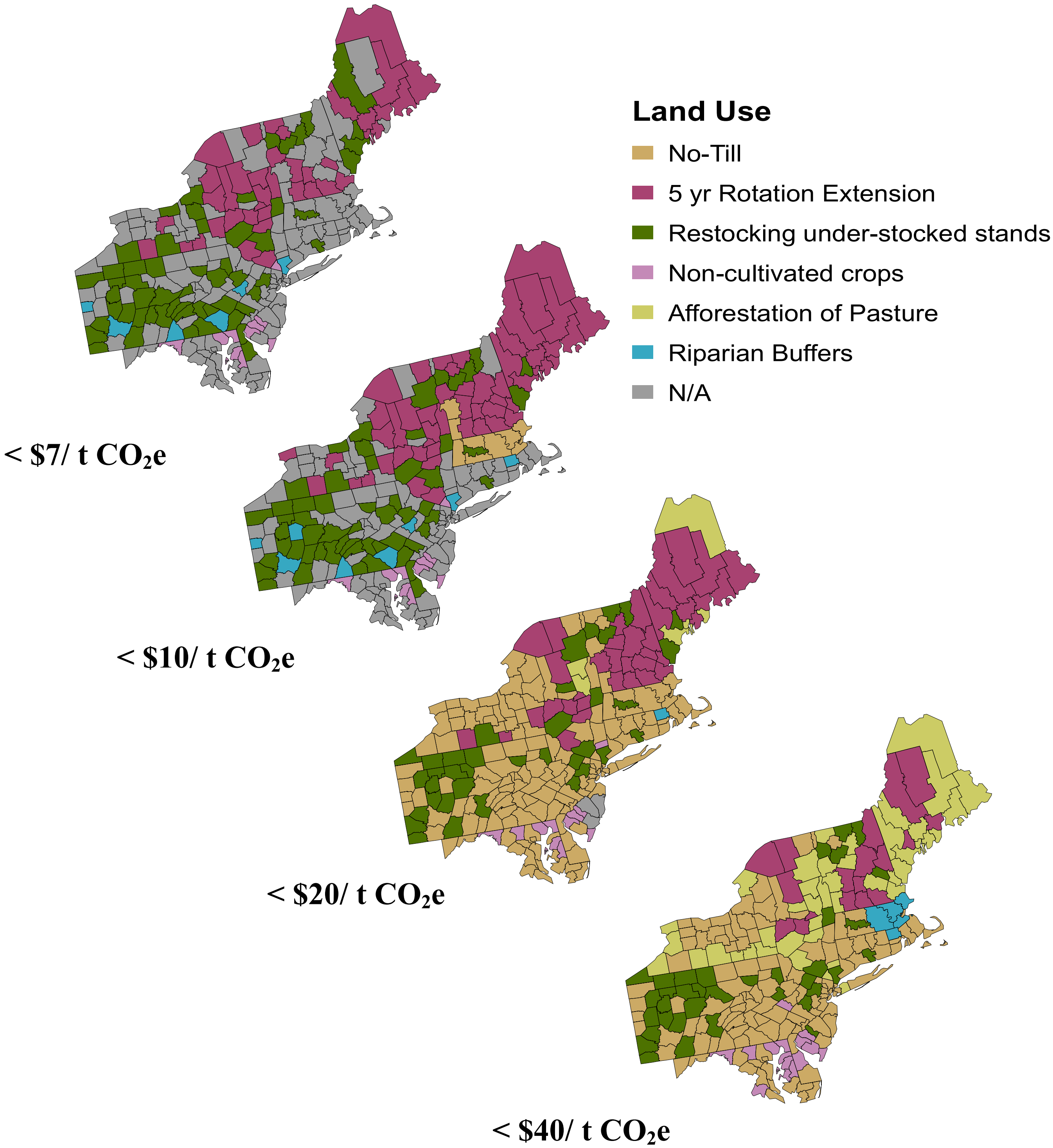


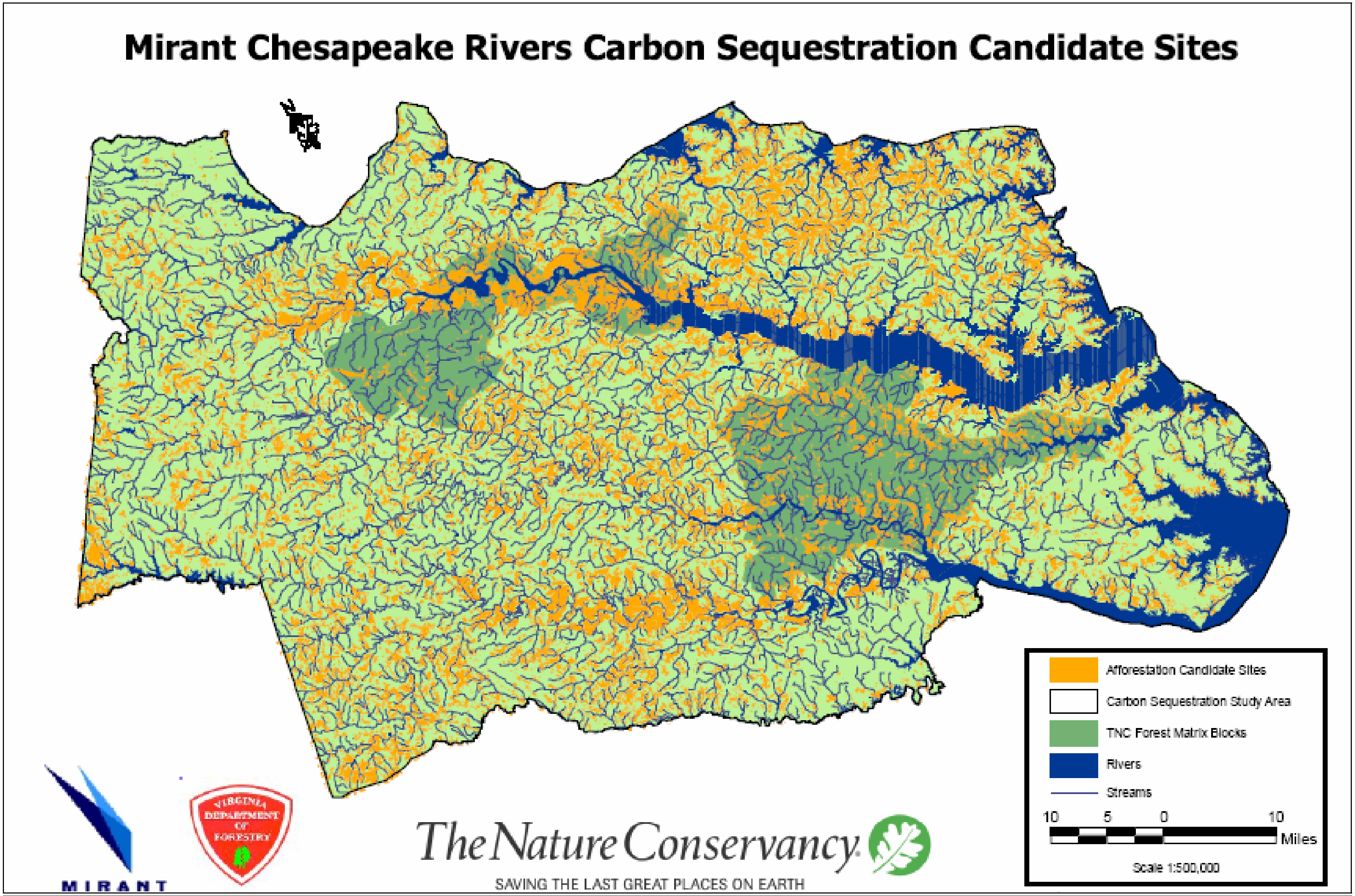
Figure 10. Land management style on agricultural or forest land with largest potential t CO_2e at various price points (at 20 yrs)

Reforestation in the Chesapeake Bay Watershed of Virginia

The site selection methodology produced a coverage of the study area which identified 18,601 eligible candidate reforestation sites totaling 384,498 acres (~10% of the study area). Mean site area was 20.67 acres (range = 1.25 to 1307 acres; 786 candidate reforestation sites in excess of 100 acres).

Applying the TNC-delineated forest matrix block boundaries, and restricting the analysis to sites greater than 100 acres in area, 111 conservation priority candidate reforestation sites were identified, totaling 26,105 acres (Figure 11). Mean site area was 235 acres. Sixteen of the 111 sites intersect with an already protected conservation area.

Figure 11. Candidate reforestation sites and TNC conservation priority forest matrix blocks in the study area.



Trends in forest cover/baseline rates of change

The time series of classified satellite imagery provided a basis for determining trends and changes in forest cover. Table 9 details county forest cover information. Core counties (in bold) are those counties which overlap well with TNC forest matrix block priorities. In the 16 counties in the study area, which cover approximately 2.7 million acres, forest cover was relatively stable between 1987/88 and 2001, covering 1.9 million acres, or approximately 70% of the study area.

Table 9. Forest cover in the study area (values in acres).

County	1987/88 Forest Cover	2001 Forest Cover
Caroline	**266,424**	**269,922**
Essex	**106,615**	**110,241**
Gloucester	104,765	104,265
Hanover	203,672	203,751
King And Queen	**148,053**	**154,860**
King George	81,608	80,889
King William	**119,816**	**121,621**
Lancaster	58,236	58,610
Mathews	38,942	39,042
Middlesex	56,468	56,479
New Kent	103,953	104,580
Northumberland	75,605	75,627
Richmond	**80,106**	**80,674**
Spotsylvania	201,146	198,083
Stafford	128,513	129,240
Westmoreland	**93,613**	**92,864**
total	1,867,535	1,880,748
Core Counties	**814,627**	**830,182**

The project team assessed changes in forest cover in the study area by disaggregating losses and gains ("new") of forest cover. Table 10 details county level data on apparent changes in forest cover for the study period.

Table 10. Apparent changes in forest cover observed between 1987/88 and 2001 in the study area (values in acres).

County	"New" forest cover (1987/88-2001)	"Lost" forest cover (1987/88-2001)
Caroline	**14,133**	**10,635**
Essex	**7,794**	**4,168**
Gloucester	3,356	3,856
Hanover	6,531	6,452
King and Queen	**12,242**	**5,435**
King George	1,647	2,366
King William	**7,041**	**5,236**
Lancaster	1,974	1,600
Mathews	1,515	1,415
Middlesex	2,002	1,991
New Kent	4,019	3,392
Northumberland	2,232	2,210
Richmond	**3,574**	**3,006**
Spotsylvania	7,480	10,543
Stafford	4,997	4,270
Westmoreland	**2,787**	**3,536**
Total	83,324	70,111
Total (Core Counties)	47,571	32,016

Forest cover change presented in this way obscures an appreciation of change in forest use. An effort was made to further define reforestation and deforestation as fundamental, and presumably longterm, changes in forest use.

According to this analysis, there was a gain of 13,213 acres in forest cover between 1987/88 and 2001. However, change in forest use followed a different trajectory. Some sites without forest cover in 1987/88 could be distinguished as recently clearcut, and subsequently with forest cover in 2001, and should thus be considered as in continuous forest use. These sites amount to 42,474 acres, and thus the total acres in forest use in 1987/88 was 1,910,009 acres (= 1,867,535 + 42,474). Furthermore, some sites without forest cover in 2001, that had been forested previously in 1987/88, could be distinguished as clearcut but still in forest management (i.e. no signs of conversion to agriculture or urban), and thus should be considered as still in forest use. These sites amount to 18,771 acres, and consequently area in forest use in 2001 is 1,899,519 acres (= 1,880,748 + 18,771). Thus, although forest cover apparently increased by 13,213 acres over the period, interpretation of the satellite imagery allows for distinguishing true or permanent changes in land use from temporary changes in forest cover, demonstrating a net loss of 10,490 acres in forest use between 1987/88 and 2001. Much (79%) of this area was converted to agriculture, which increased by

8,243 acres over the same period (575,322 acres in 1987/88 to 583,565 acres in 2001), though there may have been some errors in the classification distinguishing between agriculture and urban.

Thus, forest use conversion due to reforestation and deforestation over the 13/14 year period was 40,850 and 51,340 acres, respectively. These represent rates of 3,026 acres reforested (= 0.16% of 1987/88 acres in forest use) and 3,803 acres deforested (= 0.20% of 1987/88 acres in forest use) annually. Some of the 1,858,669 acres in continuous forest use throughout the study period undoubtedly displayed temporary loss followed by regain of forest cover, due to timber harvest and management, within the intervening period (i.e. 1989-2000).

Landowner incentive programs such as the Conservation Reserve Enhancement Program (CREP) provide funding for reforestation projects on marginal agricultural and sensitive lands. The data for this program suggest that as much as 100% of the net reforestation rate of agricultural lands may be attributed to the CREP program.

Differences in forest cover between the two sample events were too slight (0.7% change, equivalent to an annual rate of change of 0.06% for the 12 year period) to conclusively resolve. Without a quantitative accuracy assessment of classification error, we are unable to determine how much of the apparent change in forest cover we calculated (13,213 acres) was actual change, versus error in classification. Errors of omission from the NLCD classification, similarly derived from Landsat imagery, range from 24 to 85% for forest cover thematic classes at the pixel scale (corresponding Federal Region 3; USGS 2004), well exceeding the change in forest cover calculated here, and thus do not permit conclusive resolution of this magnitude of change.

Reforestation/management alternatives

Biological sequestration of carbon has the potential to contribute measurable offsets of greenhouse gas emissions. An emerging voluntary market for carbon emissions reductions has created the opportunity for landowners to expand the range of forest management goals for consideration, including timber value, wildlife habitat enhancement, and now carbon sequestration. The appropriate reforestation strategy for each landowner and/or investor will represent the optimal composite valuation of these different goals.

The Nature Conservancy and the Virginia Department of Forestry identified three reforestation/management models based on three primary project goals including (1) carbon sequestration, (2) timber value from a working forest, and (3) biodiversity/wildlife value, and three desired future conditions, including:

1) Hardwood planting to old-growth forest
The goal of this reforestation/management model is to create an old-growth forest which maximizes habitat and environmental benefits for birds, mammals and wide-ranging species. This model generates carbon sequestration and wildlife/biodiversity values.

2) Loblolly pine working forest buffer with hardwood old-growth core
The goal of this reforestation/management model is to create an old-growth core of hardwood forest (50 acres on a 100 acre tract) which is buffered by 50 acres of loblolly pine working forest. This model offers a balance of carbon sequestration, wildlife values, and timber values and community benefits from maintaining elements of the working forest landscape.

3) Loblolly pine working forest
The working forest reforestation/management model maximizes timber values while additionally offering carbon sequestration values (in both living tree biomass and long-lived wood products). Biodiversity/wildlife benefits are minimal due to the low tree species diversity and frequency of disturbance.

Reforestation/management model outcomes

Model 1: Hardwood planting to old-growth forest

At 100 years, this model would sequester 17,131 metric tons of CO_2 in living tree aboveground biomass (equivalent to 115.4 Mg C/ha). This value is actually higher than the loblolly pine working forest model, which results in 15,632 metric tons of CO_2 sequestered in living tree aboveground biomass and long-lived wood products, despite faster growth of loblolly relative to hardwoods (e.g. at 16 years, loblolly biomass carbon is 57 Mg/ha, compared with 46 Mg/ha for hardwood biomass carbon). The difference arises due to inefficiencies in harvest and processing to convert tree biomass to long-lived wood products, as well as the 1% per year retirement rate of long-lived wood products.

With establishment of a conservation easement, cost to produce one metric ton CO_2 for this alternative is \$4.50 (total present value cost \$77,500 / 17,131 tCO_2), while with outright land acquisition, cost to produce one metric ton CO_2 for this alternative is \$13.28 (total present value cost \$227,500 / 17,131 tCO_2).

Model 2: Loblolly pine working forest buffer with hardwood old-growth core

At 100 years, this model would sequester 16,110 metric tons of CO_2 (equivalent to a mean of 108.5 Mg C/ha across the hardwood and managed loblolly pine strata). With establishment of a conservation easement, cost to produce one metric ton CO_2 for this alternative is \$3.63 (total present value net cost \$58,420 / 16,110 tCO_2). Total net cost includes planting, monitoring, and conservation easement establishment costs (present value \$77,180) as well as revenues from stumpage sales from thinnings and end of rotation harvests on the 50 acres of loblolly pine working forest buffer (present value \$18,760).

With outright land acquisition, cost to produce one metric ton CO_2 for this alternative is \$12.94 (total present value cost \$208,420 / 16,110 tCO_2).

Model 3: Loblolly pine working forest

At 100 years, this model would sequester 15,090 metric tons of CO_2 (equivalent to 101.7 Mg C/ha). With establishment of a conservation easement, cost to produce one metric ton CO_2 for this alternative is \$2.61 (total present value net cost \$39,340 / 15,090 tCO_2). Total net cost includes planting, monitoring, and conservation easement establishment costs (present value \$76,860) as well as revenues from stumpage sales from thinnings and end of rotation harvests (present value \$37,520).

With outright land acquisition, cost to produce one metric ton CO_2 for this alternative is \$12.55 (total present value cost \$189,340 / 15,090 tCO_2).

CONCLUSIONS

Interesting and practical findings have resulted from the work accomplished in the January to March 2007 quarter.

Under task 5, Northeast Study, "Part 4: Opportunities for Improving Carbon Storage and Management on Forest Lands," the results indicate that for less than \$20/t CO_2e, it is possible to sequester up to 16.5 million t CO_2e in the northeastern U.S. through increasing the rotation age of forests. The aging analysis focused only on softwoods in the states of New Hampshire, Maine, New York, and Vermont. The lowest cost options for the aging analysis were found to occur with 5 year extensions of the rotation age, where average costs of sequestration in the region are around \$6/t CO_2e. Harvesting and re-stocking mature forests that currently are under-stocked is estimated to have the potential to provide up to 10.6 million t CO_2e for less than \$10/t CO_2e, and up to 12.1 million t CO_2e for less than \$20/t CO_2e. Riparian zone management in the region is fairly expensive by comparison. Although it is estimated that there are around 690,000 acres available in mature forests in 50 foot buffer strips around streams in the region, very little carbon can be sequestered for \$10 or \$20 per t CO_2e. One reason for this is that the carbon gains are smaller per acre than for the aging or re-stocking scenarios. Setting aside timberland provides temporary carbon benefits, but in the long-term, harvesting of forests in the region (with or without mill residues being used for energy production) stores more carbon.

Also under Task 5, Northeast Study, "Part 5, Environmental Co-Benefits of Carbon Sequestration Opportunities", the analysis conducted in this part of the report demonstrates one methodology for identifying priority forest and stream habitat that will result in conservation and biodiversity benefit from afforestation activities. The results merely show the subset of lands available for afforestation activities that would generate clear biodiversity and conservation benefits.

Table 7 [draft] summarizes the total area available for afforestation in priority forest habitat and stream habitat areas in the study area. In total there are 4,601,339 acres of cropland and pasture land available for afforestation in the identified priority forest habitat and 4,455,792 acres of cropland and pasture land available for afforestation in the identified priority stream habitat. The acres available for afforestation in identified priority forest habitat amounts to 34% of the total area available for afforestation in the region with New Hampshire having the greatest percentage of total area at 51% and Pennsylvania with the least at 9%. The acres available for afforestation in identified stream habitat amounts to 27% of the total area available for afforestation in the region with Delaware having the greatest percentage of the total area at 44% and Pennsylvania having the least at 16%.

Table 7 DRAFT

	Forest co-benefit			Stream buffer co-benefit		
	cropland	pasture land	Total Forest	cropland	pasture land	Total Stream
	% of area with co-benefit					
Connecticut	40%	45%	43%	34%	37%	36%
Delaware	57%	39%	48%	50%	37%	44%
Maine	35%	28%	32%	28%	28%	28%
Maryland	47%	50%	49%	18%	19%	19%
Massachusetts	30%	32%	31%	27%	27%	27%
New Hampshire	50%	52%	51%	18%	24%	21%
New Jersey	28%		28%	35%		35%
New York	20%	22%	21%	20%	20%	20%
Pennsylvania	6%	11%	9%	15%	16%	16%
Rhode Island	24%	27%	26%	31%	28%	30%
Vermont	36%	40%	38%	33%	27%	30%
Totals	**34%**	**35%**	**34%**	**28%**	**26%**	**27%**

A few additional summary tables will be included in the final version of Part 5.

Finally under Task 5, Northeast Study, “Part 6, Comparison of Opportunities,” there are many land options available to increase the carbon stocks of the land in the north east. However, which option is the most cost effective is highly spatially variable. With lower marginal costs, restocking understocked stands, extending forest rotations, and conversion to permanent vegetation are land management options available on a large area of land and with a high CO_2e sequestration potential.

Table 8. Summary of potential area and amount of emission reductions available at various price points for all land management options

Assuming 20 year period on agricultural lands, and permanent land management change in forest lands

Price Points	Afforestation		Crop Management		Biomass Energy	Forest Management		
	Cropland	Pasture	No-till	Permanent Vegetation		Restocking Understocked Stands	5 yr Rotation Extension	Riparian Buffers
	potential t CO_2e							
< $7/t CO_2e		8 million		6.6 million		10 million	8.4 million	137,000
< $10/t CO_2e		8 million	1.2 million	6.6 million	6.9 million	10.8 million	11 million	143,000
< $20/t CO_2e		21 million	32 million	7.6 million	9.7 million	12.9 million	11.6 million	201,000
< $40/t CO_2e	116,000	215 million	33 million	13 million	1.4 billion	14.3 million	11.8 million	490,000
	potential area (acres)							
< $7/t CO_2e		169,000		550,000		1 million	1.4 million	79,000
< $10/t CO_2e		169,000	110,000	550,000	35,000	1 million	1.9 million	87,000
< $20/t CO_2e		351,000	5.7 million	636,000	48,000	1.3 million	2.1 million	123,000
< $40/t CO_2e	2000	3.6 million	5.7 million	1 million	7 million	1.5 million	2.2 million	193,000

Also under Task 5, Reforestation in the Chesapeake Bay Watershed of Virginia, the project team collected data necessary to identify sites for reforestation in the study area, environmental data for the determining site suitability for a range of reforestation alternatives and has identified and addressed potential leakage and additionality issues associated with implementing a carbon sequestration project in the Chesapeake Rivers Conservation Area. Furthermore, carbon emissions reductions generated would have strong potential for recognition in existing reporting systems such as the U.S. Department of Energy 1605(b) voluntary reporting requirements and the Chicago Climate Exchange.

This study identified 384,398 acres on which reforestation activities could potentially be sited. Of these candidate sites, sites totaling 26,105 acres are an appropriate size for management (> 100 acres) and located in priority conservation areas identified by The Nature Conservancy. Total carbon sequestration potential of reforestation in the study area, realized over a 100 year timeframe, ranges from 58 to 66 million tons of carbon dioxide equivalent, and on the priority sites alone, potential for carbon sequestration approaches or exceeds 4 million tons of carbon dioxide equivalent. In the absence of concerted reforestation efforts, coupled with policy strategies (Commonwealth of Virginia 2005), the region will likely face continued declines in forest land.

REFERENCES

Anderson, M. G., A. Olivero, C. Ferree, D. Morse, S. Khanna, in collaboration with the Eastern Region Conservation Measures Team. 2006. Conservation Status of the Northeastern U.S. and Maritime Canada. The Nature Conservancy.

Commonwealth of Virginia. 2005. A continuing study on the provision of incentives to preserve private forest land in the Commonwealth of Virginia. Senate Joint Resolution 367, Board of Forestry, Virginia Department of Forestry.

Hardie, I.W., Parks, P.J., Gottlieb, P. and D.N. Wear. 2000. Responsiveness of Rural and Urban Land uses to Land Rent Determinants in the U.S. South. *Land Economics* 78:659-73.

Mooney, S. 2003. Measurement and monitoring costs: influence of parcel contiguity, carbon viability, project size and timing of measurement events. Winrock International. Arlington, Virginia. 34 pp.

Smith, J., Heath, L. and J. Jenkins. 2003. Forest volume-to-biomass models and estimates of mass for live and standing dead trees of U.S. forests. USDA Forest Service, Northeastern Research Station, GTR NE-298

The Conservation Fund and USDA Forest Service. 2006. The State of Chesapeake Forests.

United States Geological Survey (USGS). 2004. Accuracy Assessment of 1992 National Land Cover Data. Available online at http://landcover.usgs.gov/accuracy/index.php

Wear, D. N. and J.G. Greis. 2002. Southern forest resource assessment: summary report. Gen. Tech. Rep. SRS-54. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 103 pp.

Winjum, J.K., Brown, S., and B. Schlamadinger. 1998. Forest harvests and wood products: sources and sinks of atmospheric carbon dioxide. Forest Science Vol 44(2): 272-284.